Relationship between resource use, efficiency and sustainability of sheep-crop farming systems

Tamara Rodríguez-Ortega, Alberto Bernués, Ana Mª Olaizola
Introduction

- “Agriculture is a primary activity by which human societies channel renewable energy flows into products that support social welfare” (Rydberg and Haden, 2006).

**EMERGY:** Energy of the same form (solar emjoules) invested to make a product or service considering the quality of the different energies involved.

- **Objective:** To evaluate the emergy flowing in representative Mediterranean sheep and sheep-crop farming systems with diverse degrees of specialization, integration and intensification of production.
Material and methods: data collection

10 sheep and mixed sheep-crop farms in Aragón (Northeast Spain), from previous farm typologies

• **Initial survey (2014):**
  – family structure and labor
  – agricultural and pasture area
  – flock dynamics
  – products and destination of production
  – farm equipment

• **Monitoring during agronomic year 2014-2015,** every 2-3 months with forms:
  – crop management (inputs, doses, time of operation, fuel consumption, harvests)
  – animal feeding (grazing calendar & indoor rations) per batch
  – reproduction management
  – self-consumptions and exchanged products
  – work for third parties, hired labor and machines
Material and methods: emergy analysis

1. Emergy diagram:

2. Emergy tables:

<table>
<thead>
<tr>
<th></th>
<th>Amount (unit/yr)</th>
<th>Transformity (sej/unit)</th>
<th>Solar emergy (sej/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local renewable</td>
<td>6.75 E13 J/yr</td>
<td>2.59 E04 sej/J</td>
<td>1.75 E18 sej/yr</td>
</tr>
<tr>
<td>resources</td>
<td></td>
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</tr>
<tr>
<td>Local non-renewable</td>
<td>7.69 E11 J/yr</td>
<td>1.24 E05 sej/J</td>
<td>9.53 E16 sej/yr</td>
</tr>
<tr>
<td>resources</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purchased inputs</td>
<td>...</td>
<td>X</td>
<td>...</td>
</tr>
<tr>
<td>Labor &amp; services</td>
<td>...</td>
<td>X</td>
<td>...</td>
</tr>
<tr>
<td><strong>Yields</strong></td>
<td>3.24 E04 kg/yr</td>
<td>9.23 E13 sej/kg</td>
<td><strong>Σ = 2.99 E18 sej/yr</strong></td>
</tr>
</tbody>
</table>

3. Emergy indicators:

- **Efficiency** = \[ \frac{\text{Light}}{\text{sun} + \text{plant} + \text{sheep}} \]
- **Intensity** = \[ \frac{\text{sheep}}{\text{area} \times \text{time}} \]
- **Self-sufficiency** = \[ \frac{\text{sheep}}{\text{sun} + \text{plant} + \text{sheep}} \]
- **Environmental stress** = \[ \frac{\text{sun} + \text{plant}}{\text{sheep}} \]
- **Sustainability** = \[ \frac{\text{Self-sufficiency}}{\text{Environmental stress}} \]
Results: diversity of farming systems

<table>
<thead>
<tr>
<th>Feeding strategy (% of year)</th>
<th>Specialized sheep-mountain pastures (S-MP) system</th>
<th>Fully-integrated mixed sheep-permanent crops (S-PC) system</th>
<th>Partially-integrated mixed sheep-arable crops (S-AC) system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grazing</td>
<td>93</td>
<td>78</td>
<td>25</td>
</tr>
<tr>
<td>Indoor</td>
<td>7</td>
<td>22</td>
<td>75</td>
</tr>
</tbody>
</table>

Grazed pastures (% of year):
- Semi-natural vegetation
- Forages
- Stubbles

Crop harvest (kg DM)
- Specialized sheep-mountain pastures (S-MP) system: 8.922
- Fully-integrated mixed sheep-permanent crops (S-PC) system: 68.738
- Partially-integrated mixed sheep-arable crops (S-AC) system: 373.592

Self-consumption (%)
- Specialized sheep-mountain pastures (S-MP) system: 100
- Fully-integrated mixed sheep-permanent crops (S-PC) system: 100
- Partially-integrated mixed sheep-arable crops (S-AC) system: 35

Sales (%)
- Specialized sheep-mountain pastures (S-MP) system: 0
- Fully-integrated mixed sheep-permanent crops (S-PC) system: 0
- Partially-integrated mixed sheep-arable crops (S-AC) system: 65
### Results: Input composition of emergy flow (emergy/year)

<table>
<thead>
<tr>
<th>Natural resources</th>
<th>Purchased inputs</th>
<th>Labor &amp; services</th>
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<tbody>
<tr>
<td>Renewable (rain-ET)</td>
<td>Food</td>
<td>Chemical fertilizers</td>
</tr>
<tr>
<td>Non-renewable (topsoil)</td>
<td>Fuel</td>
<td>Slurry</td>
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<td></td>
<td>Electricity</td>
<td>Pesticides</td>
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<td></td>
<td>Seeds</td>
<td>Water</td>
</tr>
</tbody>
</table>

#### Emergy flow:
- 2.99E18 sej/yr
- 1.69E18 sej/yr
- 2.63E18 sej/yr
- 2.99E18 sej/yr
- 1.64E18 sej/yr
- 1.97E18 sej/yr
- 5.53E16 sej/yr
- 6.21E16 sej/yr
- 4.52E17 sej/yr
- 1.86E17 sej/yr
- 2.33E17 sej/yr
- 1.22E17 sej/yr

#### Percentage of emergy flow:

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</thead>
<tbody>
<tr>
<td>S-MP</td>
<td>S-AC</td>
<td>Farming systems</td>
<td>Individual agricultural products</td>
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</tbody>
</table>
Results: Emergy embeded on agricultural products

Solar emjouls (sej) per J of product:

- **Specialized sheep-mountain pastures (S-MP) system**
- **Fully-integrated mixed sheep-permanent crops (S-PC) system**
- **Partially-integrated mixed sheep-arable crops (S-AC) system**
Results: Emergy footprint of lamb meat, but what about composition?

Emergy per kg of lamb meat sold (live weight):

- **Specialized sheep-mountain pastures (S-MP) system**
  - Emergy: 9.23E+13 sej/kg
- **Fully-integrated mixed sheep-permanent crops (S-PC) system**
  - Emergy: 9.83E+13 sej/kg
- **Partially-integrated mixed sheep-arable crops (S-AC) system**
  - Emergy: 6.95E+13 sej/kg

### Units:
- %
- E+13 sej/kg

#### Renewable natural resources
- ↓ efficiency (high external feed during lactation due to dry spring)

#### Non-renewable natural resources
- ↓↓ efficiency (high mortality)

#### Purchased inputs

#### Labor and services

- ↑ efficiency
Results: Trade-offs on production models

- Specialized sheep-mountain pastures (S-MP) system
- Fully-integrated mixed sheep-permanent crops (S-PC) system
- Partially-integrated mixed sheep-arable crops (S-AC) system

Lamb meat

+ crops

System

Efficiency

Intensity → Sustainability

Trade-offs on production models
Conclusions

1. The production system determines the origin and quantity of resources that are incorporated in agricultural products.

2. Intensification (higher inputs of non-renewable resources allowing more production in smaller spaces and faster times), while yielding more product per unit of emergy input (i.e. higher efficiency), also results in products having lower self-sufficiency and higher environmental stress, thus contributing to lower sustainability.

3. Footprint indicators (e.g. emergy) need to be complemented with other indices to get a more holistic view of agricultural production.
Does intensification result in higher efficiency and sustainability? An emergy analysis of Mediterranean sheep-crop farming systems

T. Rodríguez-Ortega a,c,*, A. Bernués a,c, A.M. Olaizola b,c, M.T. Brown d

a Centro de Investigación y Tecnología Agroalimentaria de Aragón (CITA), Zaragoza, Spain
b Departamento de Ciencias Agrarias y del Medio Natural, Universidad de Zaragoza, Zaragoza, Spain
c Instituto Agroalimentario de Aragón – IA2 – (CITA-Universidad de Zaragoza), Zaragoza, Spain
d Department of Environmental Engineering Sciences, University of Florida, Gainesville, USA
Material and methods: emergy analysis